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Geothermal energy-convenient heat source for renewal and new development of protected crop cultivation in Macedonia

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ABSTRACT

Economy transition of Macedonia underlined the weak points of protected crop cultivation sector. Beside the others, high energy costs, decreased competitiveness of it to the import and stopped the development. By analysis of the composition of the energy costs, available, and applied heating technologies and heat sources on disposal, a trial is made to recommend a sustainable solution, which can enable to make the production more competitive and to initiate a new process of development. Geothermal energy has already been identified as optimal choice. Country is rich with this energy source, spread in the regions with long tradition of protected cultivation. Available technologies for geothermal heating of greenhouses enable to reach needed low price of used heat and prevent of negative environmental impacts, which are characteristic for the fossil fuels used for the same purpose, and increase employment in poor rural areas of the country.

Contents

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1. Introduction

Protected crop cultivation has been quite important agricultural production sector in Macedonia before 1991. It has been covering nearly 90% of the out-of-season vegetable consumption of ex-Yugoslavia and a good part has been exported. However, economy transition process of the country and two embargoes (of Greece and NATO) resulted with the lost of previous major markets and increase of the price of heavy oil with un-competitiveness to the other Mediterranean producers. On the contrary, most of the greenhouses complexes which are using geothermal energy for covering the heat demand, not only survived this difficult period but have been and are realizing excellent profits, even without modernization of the growing technologies [12].

Now, when the economy begin to show the first signs of recovery, interest for starting a new development process of this production sector is in increase and investigations for the characteristics of it are in flow. Positive experience with geothermal energy takes place in them in order to use optimally the available benefits but with incorporation of necessary technical/technological improvements, proven meanwhile in neighboring and other countries.

In order to give a positive contribution to that, a study of available geothermal energy resource in Macedonia is made, its distribution in combination with the distribution of out-of-season production sector, possibilities offered by the contemporary technologies for heating greenhouses with low temperature heating systems in relation to requests of different cultures, and possible development, based on combination of positive and negative factors in the country and at the market.

2. Geothermal resources in the case study region

2.1. Geological framework and tectonic settings of Macedonia [1]

Rocks of different age occur, starting from Precambrianto Quaternary at the territory of Macedonia (Fig. 1). Almost alllithlogical types are represented. The oldest, Precambrianrocks, consist of gneiss, micaschists, marble andorthometamorphites. The rocks of Paleozoic age mostlybelong to the type of green schists, and the Mesozoic onesare represented by marble limestones, acid, basic andultrabasic magmatic rocks. The Tertiary sediments consist offlysch and lacustrine sediments, sand-stones, lime-stones, clays and sands.

With respect to the structural relations the territory can be divided into six geotectonic units: The Cukali-Krasta zone, West Macedonian zone, Pelagonian horst anticlinorium, Vardar zone, Serbo-Macedonian massif and the Kraisthide zone (Fig. 2). This tectonic setting is based on actual terrain and geological data without using the geotectonic hypothesis. First four tectonic units are parts of Dinarides, Serbo-Masedonian mass is part of Rodops and the Kraisthide zone is part of Karpato-Balkanides distinguishedon the Balkan peninsula as geotectonic units of first stage.

2.2. Geothermal background [1]

The territory of the Republic of Macedonia belongs tothe Alpine-Himalayan zone, with the Alpine sub-zone havingno contemporary volcanic activity. This part starts from Hungary, across Serbia, Macedonia and North Greece and stretches to Turkey. Several geothermal regions have been distinguished including the Macedonian region, which is connected to the Vardar tectonic unit. This region shows positive geothermal anomalies and is hosting different geothermalsystems. The hydrogeothermal systems, at the moment, are the only ones that are worth for investigation andexploitation.

There are 18 geothermal known fields in the country (Fig. 2) with more than 50 thermal springs, boreholes and wells with hot water. This discharge is up to 1.000 l/s water flow with temperatures of 17–79 °C. Hot waters are mostly of hydrocarbonate nature, according to their dominant anion, and mixed with equal presence of Na, Ca and Mg. The dissolved minerals range from 0.5 to 3.7 g/l.

All thermal waters in Macedonia are of meteoric heat source is the regional heat flow, in the Vardar zone is about 100 mW/m^2 and crust thickness 32 km. Only the Kocani, Vinica, Strumica and Gevgelija geothermal fields have been put in operation with energy uses (agriculture). There are also balneological uses of the Debar, Skopje, Kumanovo, Gevgelija and Strumica geothermal fields (Fig. 3).

Most of agricultural uses are developed during the 1980s of last century in the Kocani, Vinica, Strumica and Gevgelija geothermal fields (Fig. 2).

3. Overview of greenhouse production sector in Macedonia [12]

Greenhouse production sector in Macedonia has been mostly developed during the 1970s and 1980s of the last century, with start in 1960s. Strange enough, but one of the first projects has been the glasshouse in Bansko (Strumica), the first geothermally heated greenhouse in the world (1964).

Two lines of development have been characteristic:

- Simple non heated soft plastic covered tunnels for growing vegetables. Total area reached up to 5000 ha in the late 1980s (Fig. 4); and
- Modern, fully equipped glasshouses in 6 ha unit complexes for growing vegetables and flowers (Fig. 5), heated with heavy oil and, later on, some of them with geothermal energy. Until 1985 a total of 225 ha have been reached, of which 50 ha has been geothermally heated.

Both lines have been successful. The first one with concentration of production from late May until early July and the second one from late March until late June. Taking into account that during that time only Netherlands in Western Europe and Hungary and Bulgaria in Eastern Europe have been export orientated, market conditions have been excellent. Practically, before 1st of May, market was completely open and prices of products have been so high that covered any production costs. Even May and June have been convenient because Dutch production was much more expensive due to the high energy costs.

Such convenient market conditions lasted until early 1980s, when high energy costs decreased profitability of the glasshouse production. However, combination of glasshouses and soft plastics covered greenhouses was still good accommodated to the market conditions and profitability was higher than the ones of other agricultural sectors. That was the reason why no real attention has been paid to the modernization of greenhouse constructions, introduction of new production technologies and energy efficiency measures in order to decrease the energy consumption in glasshouses.

During the period from 1991 to 1995 situation has been completely changed. The war in Yugoslavia and its disintegration, embargoes of Greece and NATO completely destroyed the market for Macedonian vegetables and flowers. Plus, economy transition with privatization of production sector destroyed the organization of commercial sector for supply of products. That resulted with practical collapse of the sector. Only most of the glasshouses heated with geothermal energy survived and a small part of the production in tunnel greenhouses.

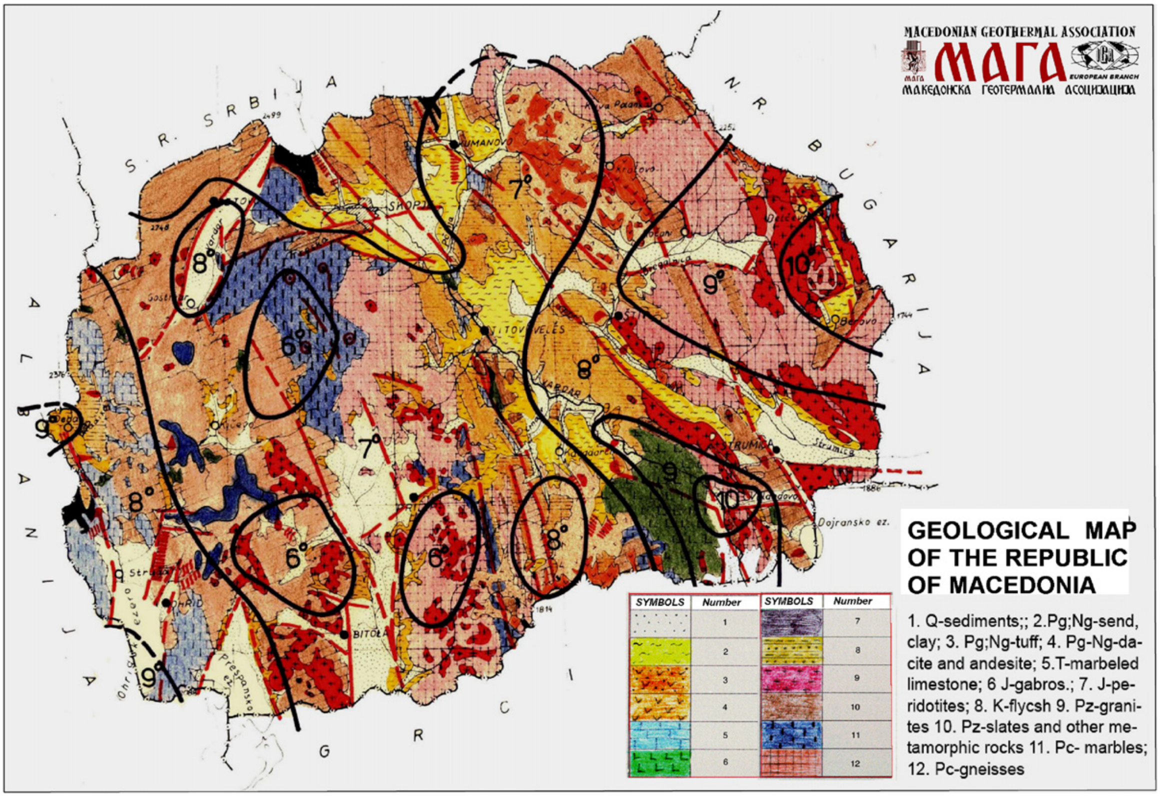

Fig. 1. Geological map of Macedonia (1, Q-sediments; 2, Pg-Ng-send, clay; 3, Pg-Ng-tuff; 4, Pg-Ng-dacite and andesite; 5, T-marbeled limestone; 6, J-gabros; 7, J-peridotites; 8, K-flycsh; 9, Pz-granites; 10, Pz-slates and other metamorphic rocks; 11, Pc-marbles; 12, Pc-gneisses) (Arsovski [1]).

Renewal of the sector began after the year 2000 but under very inconvenient conditions. Competition of the products from other Mediterranean countries, particularly from Turkey (developed meanwhile) has been to strong for the old fashioned and more expensive Macedonian producers. Until now, only a part of the market in neighboring countries is returned. Except the geothermally heated ones, glass-houses are working without heating, i.e. with a late spring and early summer production and the area of soft-plastics covered tunnels is decreased for 3–4 times in comparison with one of the 1980s of last century. Obviously, full renewal of the production sector is not possible without introduction of modern glasshouse's and soft plastics covered greenhouse's constructions, modern and more productive technologies, introduction of energy efficiency measures and new and cheaper energy sources for covering the heat demands of the production. Problem under attention of this study is the investigation of possibilities and justifiableness of wider application of geothermal energy as energy source in order to decrease energy costs of the production. In that way, a strong argument for organization of a new development cycle can be get and interest of investors supported.

4. Greenhouse as heat consumer

When agricultural sector is in question, geothermal energy has been used most extensively for heating greenhouses. Many European countries, particularly in the Mediterranean and South East European region, are regularly using it for commercial out-of-season production of vegetables, flowers and fruits. That is one of the most important direct uses of geothermal energy not only in the region but in the World.

Although not in order of importance, main reasons for choosing geothermal energy in this sector are [2]:

(a) Good correlation between the location of some greenhouse production areas and low enthalpy geothermal reservoirs.
(b) Greenhouses are one of the largest low-enthalpy energy consumers in agriculture.
(c) Geothermal energy requires relatively simple heating installations for basic Mediterranean simple plastic greenhouses but advanced computerized systems can be added later for total conditioning of the inside climate in the greenhouses.
(d) Economic competitiveness of geothermal energy for greenhouse heating in many situations.
(e) Strategic importance of energy sources that are locally available for food production.

Even, at the first view, rather simple problematics, designing of a technically successful and economically justified geothermal system for heating greenhouses is rather complex and complicated, particularly when time programmed production is in question. It requires good knowledge of the characteristics and energy requests of grown culture, type of greenhouse construction, characteristics of local climate, etc. [3].

By definition, greenhouse is a space bounded by transparent partitions, in which should be possible to maintain a desired "climate", that is different from the climate outside the greenhouse. There are four physical phenomena that play a major role in creating these differences in climate [4]:

(a) Solar radiation, in particular the short waves, penetrates the glass or plastic film covering the greenhouse with practically no loss of energy. On reaching the soil surface, the plant canopy and the heating and other installations, this radiation changes to long wave. As long waves are unable to penetrate the walls of the greenhouse as easily as short waves, the energy is trapped within the enclosed space.

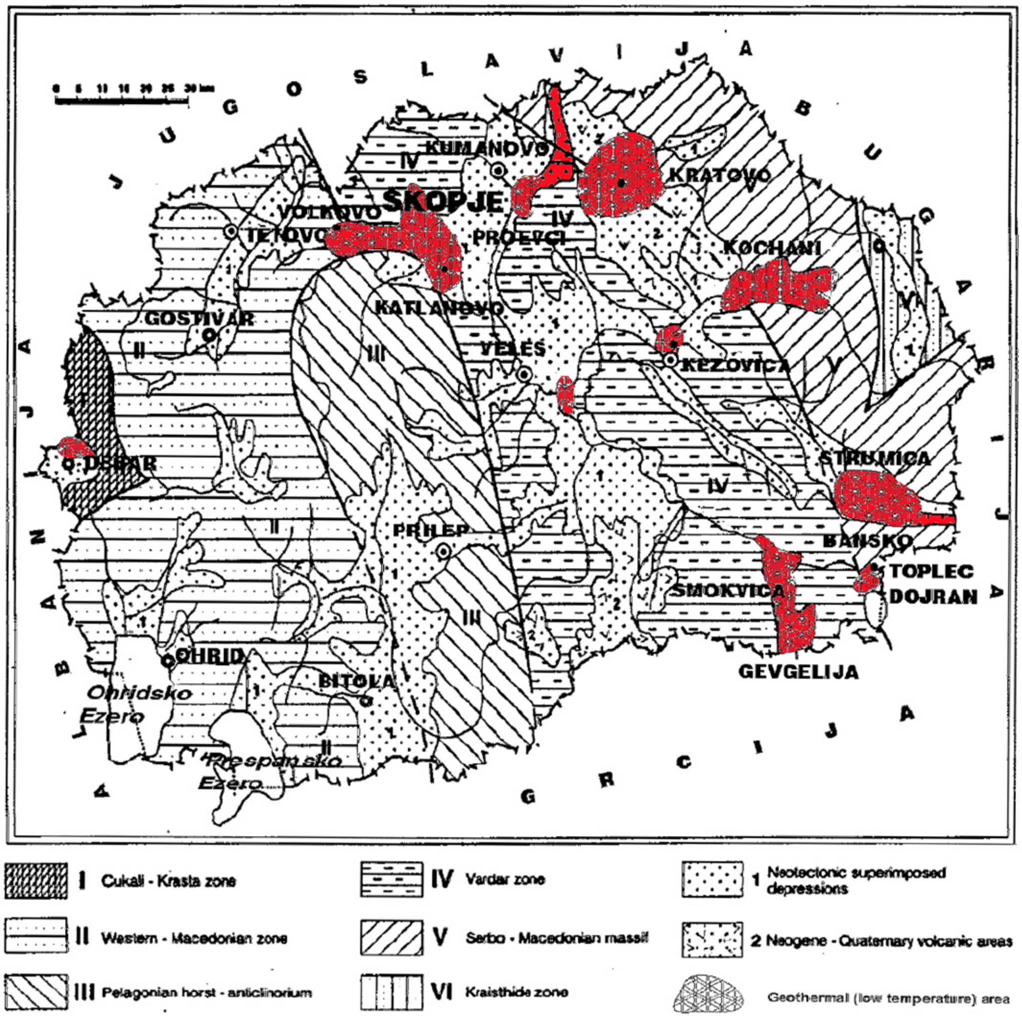

Fig. 2. Main geothermal fields in Macedonia.

(b) The air within the greenhouse is stagnant.
(c) The concentration of plant mass in a protected space is much higher than outside, so that mass transfer is different.
(d) The presence of heating and other types of systems changes some of the energy factors of greenhouse climate.

All the listed phenomena involve physical parameters that control the plant growth process and heat consumption of the greenhouse. We will now discuss these parameters [7,8]:

4.1. Light

This is the most important parameter in plant growth All the other parameters depend directly on light intensity It should be stressed at this point that only radiation with wavelengths between 400 and 700 nm influence the intensity of plant life processes.

4.2. Temperature

The transfer of energy from the environment to the plant is governed by plant temperature. This transfer of energy is influenced mostly by the surrounding air temperature but also by the temperature of the soil and of other elements of the environment (greenhouse construction, installations, etc.) (Fig. 6).

Optimum development of plant life processes depends directly on the level of plant temperature, which depends on the intensity of light available, i.e. the higher is the intensity of light, the higher the requested optimal plant temperature.

4.3. CO_2 concentration

The CO_2 in the atmosphere around the plant is used to form the plant ‘building’ materials, such as sugars. Its transformation is governed by light intensity and plant temperature. The higher the intensity of the light and the temperature, the higher must be the concentration of CO_2 in the air.

4.4. Air movement

Air movement in a greenhouse influences the transfer of heat between the plant and the air, and the exchange of water between them. Different plant species require different types of air movement for optimum growth.

4.5. Water transport

Water is also an important element for production of the plant ‘building’ materials. The plant “takes” in water from the surrounding air and from the soil around its root system. Optimum conditions of air and soil humidity will, however, depend on the type of plant and its stage of development.

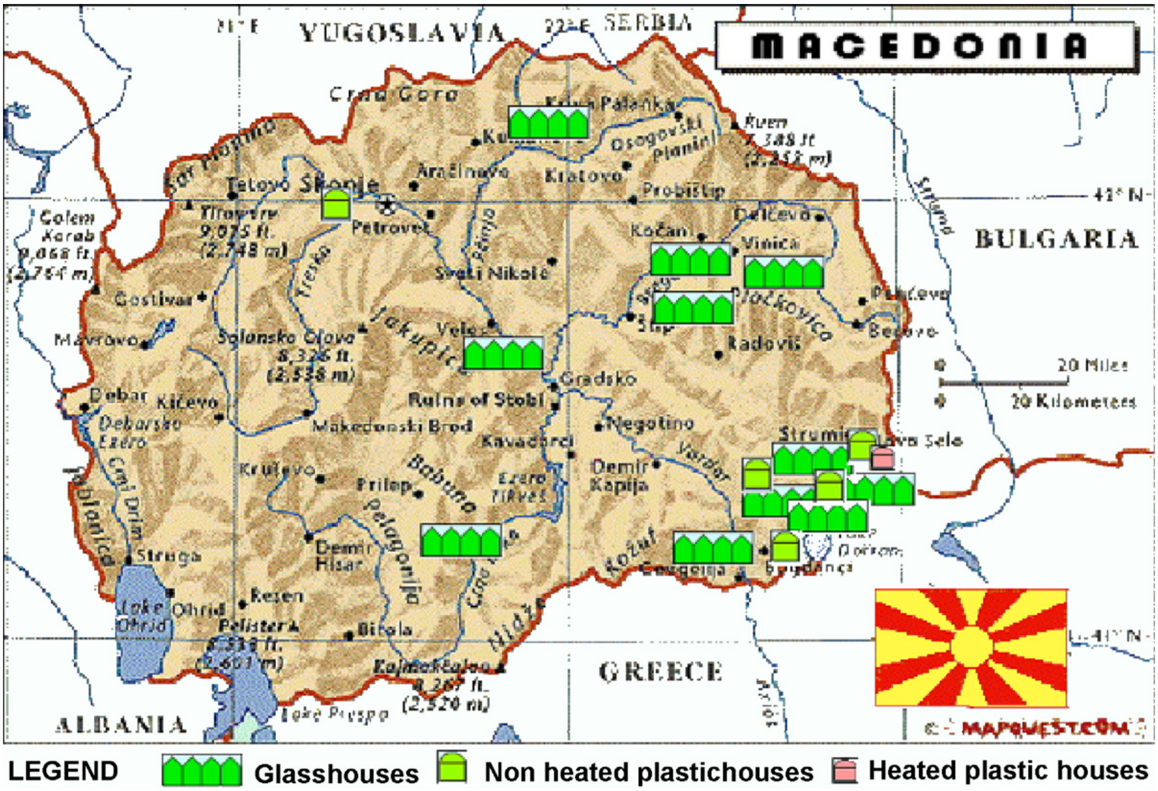

Fig. 3. Disposition of greenhouse production in Macedonia.

4.6. Heating installation(s)

The heating system(s) affects air and soil temperature, but also influences the type and velocity of inside air movement Therefore it plays an active role in “building” the plant energy balance [9].

4.7. Cooling installation(s)

Cooling installations are also an active element in creating the greenhouse climate as they influence air temperature and humidity.

There are other elements that also affect greenhouse climate such as: the type of construction of the greenhouse, the materials used for the transparent walls, the type of crop and its stage of development, etc.

The optimum greenhouse climate i.e. the climate that will permit optimum plant growth depending on the available light intensity and quality, result of a compromise between the optimal values of each of the above parameters or elements These values are interdependent and at times may be contradictory [4].

Greenhouse is by nature of its construction a large energy consumer due to the absence of any thermal insulation or inertia of the construction material [17]. On the other hand, it is a particular solar collector enabling to capture solar heat rather efficiently (Fig. 6). That results with a rather uneven daily (Fig. 7) and annual heat consumption (Fig. 8). Peak loadings appear in early morning hours during the winter months and cloudy days. However, they are very short and last only until the sun appear and greenhouse start to relate as a solar collector.

We can therefore conclude that heat consumption of a greenhouse varies on a daily and annual basis, with rather short periods of maximum heat demand. Over a 12-month period, it mainly depends on changes in the outside air temperature and in the intensity of solar radiation (Fig. 8). When covering of the total annual heat demand is in question, we can make a distinction between the base heat requirements lasting all over the heating season, and the peak loadings, appearing during the mornings and cloudy days in winter months and lasting very short (Fig. 9). That is having consequences to the choice and design of the heat source for covering

Fig. 4. Soft plastics covered tunnel greenhouses in Bansko (photo by Popovski, 1997).

Fig. 5. Glasshouse complex in Kocani (Popovski [15]).

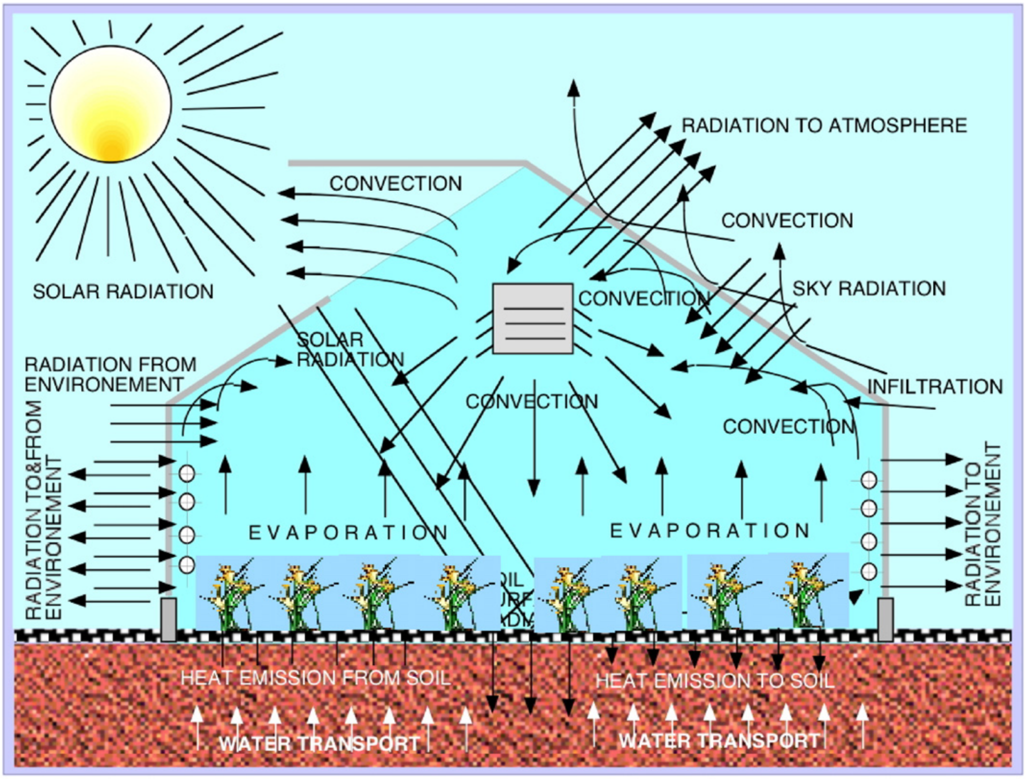

Fig. 6. Heat flows in a greenhouse.

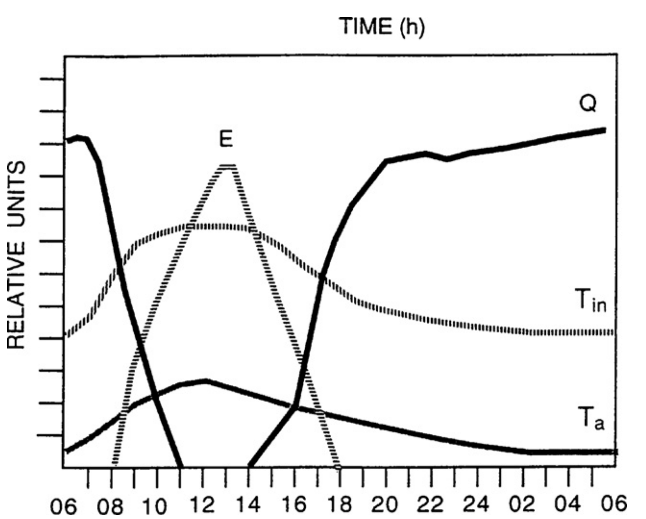

Fig. 7. Heat requirements fluctuations in a greenhouse. Average conditions in January in a greenhouse in Gevgelia, Republic of Macedonia (Popovski [14]). *E*, solar radiation energy flux (Wh/m^2); T_a, outside air temperature (°C); T_{in}, optimal internal air temperature (°C); *Q*, greenhouse heat requirements.

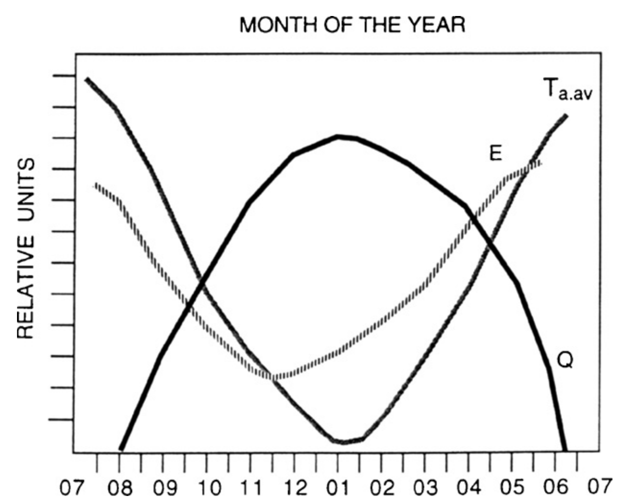

Fig. 8. Heat requirements fluctuations in a greenhouse over a typical year in Gevgelia, Republic of Macedonia (from Popovski [14]). *E*, solar radiation energy flux (Wh/m^2); $T_{a.av}$, monthly average outside air temperature (°C); *Q*, greenhouse heat requirements.

the heat demands i.e., if covering the heat demands with a heat source requesting high investments, it is normally more economically to cover the peak loadings with some additional heat source, requesting low investments in completion [4,18].

5. Technologies for heating greenhouse interior

Heating system is the term commonly used for the heat exchangers providing supplementary heat in greenhouses. The temperature of the heating fluid and particular plant requirements in the greenhouse dictate its design, location, material, means of regulation, etc. The level of sophistication depends on the technological level of production, greenhouse construction, requested climate characteristics, other technical and economical factors.

There are two extreme technological solutions, encompassing a wide spectrum of intermediate schemes, i.e.:

(a) Simple heating systems using plastic or steel pipes for transport of heating fluid from the source to the greenhouse and transfer of heat in it. The aim of this type of systems is normally only to improve the inside temperature conditions all year round, in mild winter climatic conditions, or during early spring and late autumn in more severe climates [5]. It is in use

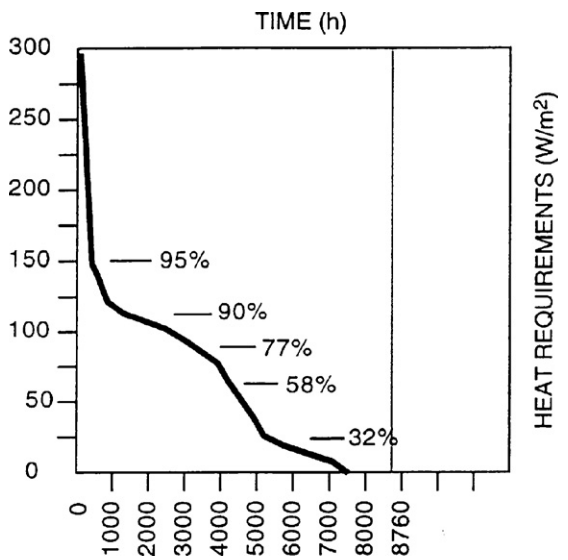

Fig. 9. Hourly distribution of calculated heat requirements in Middle European conditions (van den Braak [10]).

in cheap soft plastic covered greenhouses in Mediterranean climate conditions. They are not technologically suitable for controlled intensive production.

(b) Sophisticated systems for total air-conditioning, with automatic regulation of the heat supply. Factors influencing heat requirements are indoor and out-door conditions, plant growth and production schemes. These systems are economically justified in expensive glass or rigid plastic constructions, equipped with technology for intensive production.

Mostly used heat exchangers now-a-days for transfer of heat into the greenhouse interior can he classified according to the type of heat transfer and location of the heating elements [4,6] (Fig. 10):

(a) Aerial pipe heating systems
(b) "Vegetative" heating systems
(c) Heating systems for growing plants on benches
(d) Side fan-assisted convector air heating systems
(e) Soil heating systems
(f) Fan-assisted air heaters
(g) Fan-assisted air heaters with plastic tube for hot air distribution.

In addition, there are a list of other non-standard systems and different combinations of listed systems able to cover specific technological and economic requirements.

Most important characteristics can be grouped in:

(a) Aerial pipe heating systems and fan-assisted air heaters need higher temperatures of the heating fluid. In opposite, the soil and vegetative heating systems can use heating fluids temperatures below 40–45 °C.
(b) Each type of heating system creates different vertical air temperature profile in the greenhouse interior (Fig. 11). Obviously, some of them are convenient for low and some for high corpus of the plant. On the other hand, some of them offer protection of the cold night radiation of the environment and some not.
(c) Each type of heating system results with different type and velocity of air movement in the greenhouse interior. That is making them convenient or not for particular plant cultures.

6. Choice of convenient heating technology for Macedonian conditions

One of the most difficult design problems in a geothermal greenhouse project is the choice of a technically, technologically and commercially feasible heating system. Each case must be judged on its own merits, taking into consideration all the influencing factors, in order to reach the optimal solution.

Primary objective of the greenhouse heating system is to maintain the temperature of the internal climate at values near to

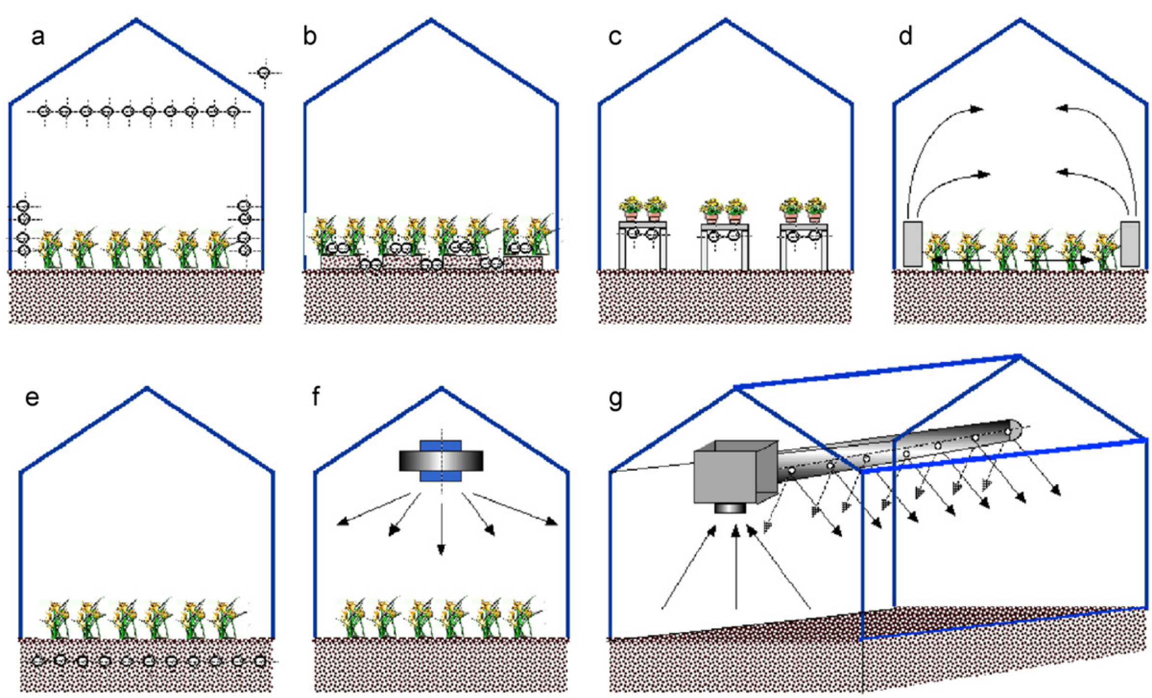

Fig. 10. Classification of low temperature greenhouse heating systems (von Zabeltitz [19]; Popovski [11]). A: Aerial pipe heating systems with natural air movement: (a) steel pipes along or above the plant canopy, (b) plastic pipes along the plant rows on the soil surface, (c) steel or plastic pipes below the growing benches; B: soil heating systems: (e) steel or plastic pipes below the soil surface; C: aerial heating with forced air movement: (d) lateral fan convectors; (f) aerial fan convector units; (g) "fan jet" system with plastic tubes with holes for air distribution.

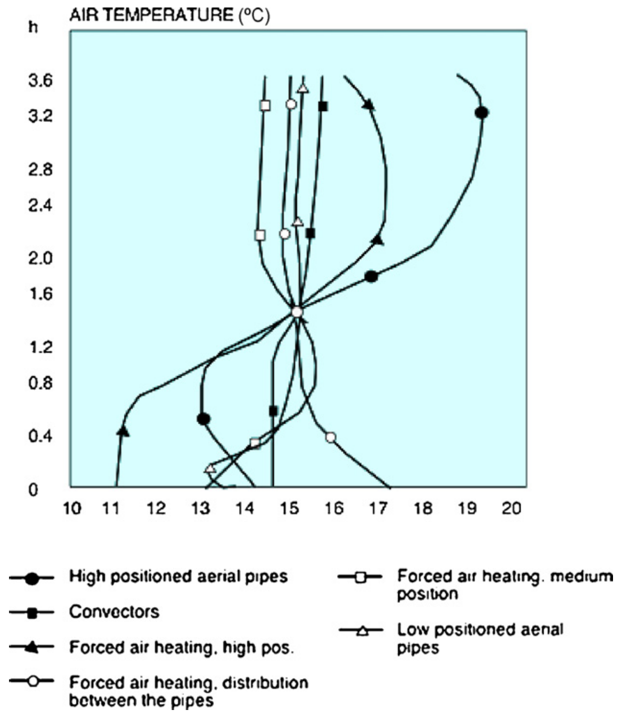

Fig. 11. Vertical air temperature profiles in a greenhouse depending on the type of heating system in it [4].

optimal. However, none of the systems we have just described will guarantee a totally uniform vertical or horizontal air temperature profile. For a reference air temperature 1.0 m above ground level (Fig. 11), the difference at ground level and below the greenhouse roof could be as high as 5–6 °C. It is obvious that such differences can he of crucial importance for the choice of heating system, depending on the stage of development and height of the grown plant culture.

Not only the height of the plant influences the choice of heating system. Also the characteristics of the local climate dictate some important limitations. Appearance of strong cold radiation of environment during the nights and early mornings can result with much lower temperature of top plant leaves than it is the average inside air temperature. In such cases, energy screens should be installed or heating system must offer convenient protection.

Different plants condition particular type of air flow and its velocity. That is limiting the choice of convenient heating system, too.

Some of the cultures condition maintenance of proper temperature of their root system. Only some of the listed heating systems offer it.

Different heating systems condition different temperature of the heating fluid, depending on their position in the greenhouse interior versus the disposition of the heated plants.

At last but not least, investment and exploitation costs are different for different heating systems. Plus, resulting heat consumption is also different. That influences the final economy of the exploitation of the greenhouse in total.

Listed influencing factors for the choice of optimal heating system in a greenhouses lead to some very important conclusions, i.e. [14]:

- There is no "universal" heating system, convenient for any type of plant, i.e. it must be chosen for concrete plant culture in order to get optimal technical end economical results of its exploitation.
- Local climate and type of greenhouse construction influence the choice of optimal heating system. If the "vegetative" heating system fulfills optimally the requirements under Mediterranean climate conditions for early spring and autumn production of vegetables in soft plastic covered greenhouses, it shall not satisfies them for the winter production in high glasshouses.
- For all year around production in moderate and colder climates, no one of the listed heating systems can cover the requirements under different seasonal climate conditions. In such a case, combination of systems should be applied.
- Characteristics of the locally available heat source also influence the choice of heating system, i.e. if low temperature heating fluid is on disposal, it shall not be possible to apply heating systems requiring higher temperature of it.
- At last but not least, economy of the chosen system or combination justify the concrete choice, i.e. final product price in concrete time frame, i.e. productivity and production costs versus investment and exploitation costs, depending on combination of positive and negative influence of listed factors.

For the Macedonian climate conditions and targeted markets of the product, we must make several initial distinctions, i.e.:

- Winter production of vegetables is mainly for foreign markets with strong competition of other Mediterranean producers and the Netherland's one. Very high quality of products and precise timing of production is required.
- Spring and autumn production of vegetables is mainly targeted to some of neighboring countries and the local market. Lower prices of products at the market do not allow high investment and exploitation costs. However, as better heating is on disposal, earlier production and better prices can be reached.
- Rather mild climate is characteristic for most of the greenhouse production areas (Fig. 3). However, during the winter months quite low air temperatures and strong winds are often, resulting with strong cold radiation during the nights and early mornings.

When the most present plant cultures are in question, it is mainly tomato, cucumbers and a small part of paprika in the glasshouses. Similar is in the soft plastic covered tunnels but with a much higher participation of paprika. Only one glasshouse complex (Vinica) is used for production of flowers, i.e. roses for export.

Market for the winter production is very good and can accept even larger production. Market conditions for spring production mainly depend on the production in neighboring countries. Particular are conditions with the Greek market, where conditions often depend on the political situation, however normally there are always some constraints disturbing normal planning and supply of Macedonian products.

- Old growing technologies are applied in both types of greenhouses. Initial experience with soilless technology with programmed feeding with drip irrigation from 1980s of last century was lost meanwhile.
- Changes of cultures and introduction of modern growing technologies need careful planning and preparation of necessary educated manpower.

To conclude, for Macedonian conditions, TOR for greenhouse heating systems is:

- Low positioned simple systems for spring and autumn production in soft plastic covered tunnels. Simple, even hand regulation of heat supply can be applied for this type of greenhouses.
- Combination of low positioned systems ("vegetative" heating) for covering the base heat demands all over the season and high

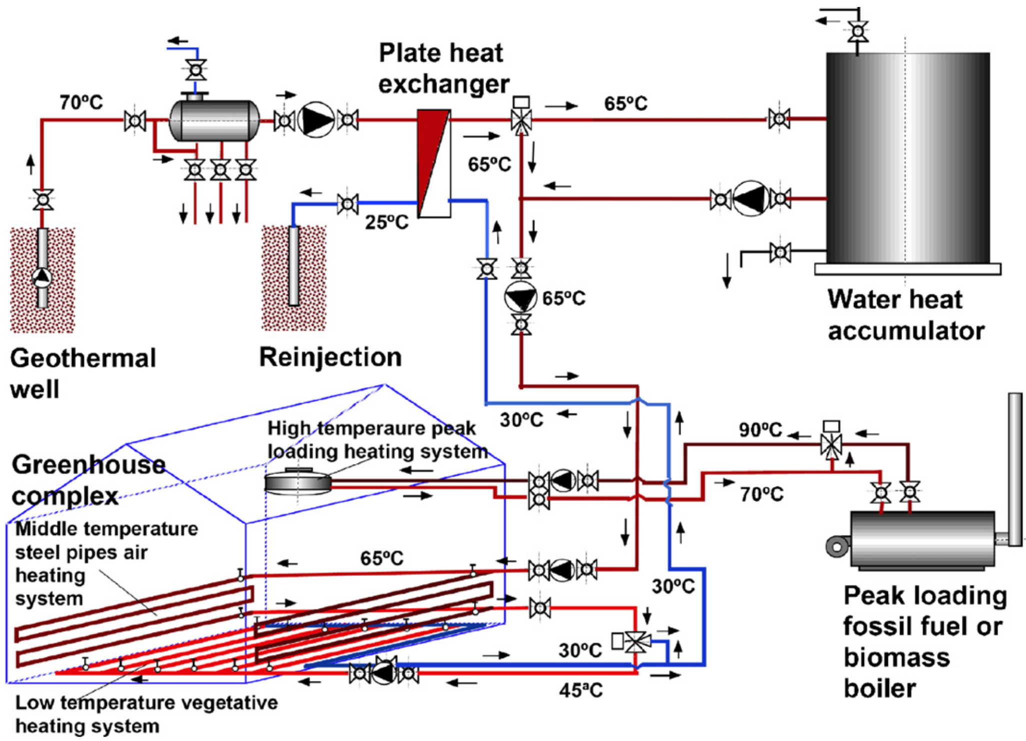

Fig. 12. Example of cascade use of geothermal heat in a sophisticated greenhouse construction by convenient heating systems for Macedonian conditions [13].

temperature high positioned systems for covering the peak heat loadings and cold radiation appearance for sophisticated fully equipped and automatically controlled growing in glasshouses and rigid plastic covered greenhouses.

- For eventual development of high soft plastic covered greenhouses, different combinations are possible, depending on the culture in question and season of production.

Taking into account the requested TOR and listed influencing factors, following types of greenhouse heating systems can be recommended:

- “Vegetative” heating system (Fig. 10b) for low soft plastic tunnels. Same type of heating system is most convenient also for high soft plastic covered greenhouses for spring and autumn production of vegetables.

This type of heating system provides natural air movement in the greenhouse and, in principle, offer better vertical temperature profiles and lower heat consumption (lower air temperatures below the cold surfaces of the roof). However, this is also one of its limitations, as they do not protect the plants from cold radiation from outside.

- “Vegetative” heating system (Fig. 10b) for covering the base heat requirements allover the season for sophisticated fully equipped greenhouses for winter and spring production of vegetables in combination with some system for aerial heating, enabling to create higher temperatures bellow the roof, for covering the peak loadings and protection of cold outside radiation. Depending on the culture in question, that can be the steel pipes aerial heating (Fig. 10a) or the use of fan-assisted air heaters (Fig. 10f). Depending on particular type of heating fluid, even the third installation can be added in order to enable cascade use of temperature of the heating fluid on disposal. As illustration, such combination (for geothermal energy use) is presented at the Fig. 12, enabling full use of the temperature difference on disposal of the heating fluid and 90% covering of total heat consumption with cheap energy source (Fig. 13).

Governing the heat supply according to the requests of inside (changeable) climate and external influencing factors should be automatic, according to the defined schemes for concrete cultures.

When making concrete choice for high positioned heating systems, it is necessary to take into account the resulting shading caused by its installation. Ideally, there should be as little shading as possible of incoming solar radiation. For low growing plants medium and high positioned heating elements should be avoided. High growing plants, on the other hand, should receive heat directly on the plant canopy from high positioned elements.

Greenhouse construction can limit the choice of heating system. Heavy heating elements cannot be hunged on cheap lightweight

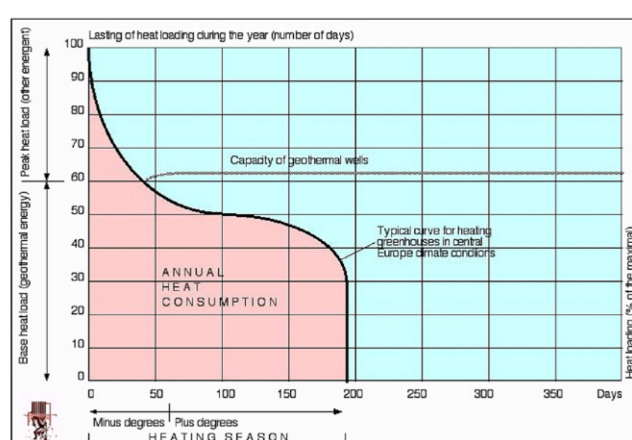

Fig. 13. Annual distribution of greenhouse heat consumption over a typical year in Macedonian conditions. Example for optimal covering with geothermal energy as base heating (Popovski [13]).

Table 1
Prediction of feasible development of geothermal energy resource in Macedonia (Popovski et al. [16]).

No.	Location of geothermal field	Temperature of appearance, °C	Flow, l/s	Heat power, MW	Expected temperature, °C	Expected flow, l/s	Expected heat power, MW	Heat power with reinjection and pumping, MW
1	Bansko[a]	68	55	9.89	60–100	100–140	32.65	55.55
2	Volkovo	22–25	85	3.29	40–70	80–100	15.10	26.07
3	Debar Kosovrasti	40–4848	15–100100	6.2812.56	40–4848–50	80–120120–150	13.8119.21	24.4832.67
4	Dojran[a]	20–25	12	0.35	60–80	80–100	17.27	29.36
5	Istibanja[a]	66.5	21.2	4.52	60–70	50–70	12.56	12.56
6	Katlanovska banja	21–38	4.2	0.4	50–60	20–50	6.70	11.38
7	Kozuf	21–28	8.8	0.36	50–60	80–120	14.40	24.48
8	Kratovo[b]	28–31	9.5	0.56	60–80	120–180	20.70	50.49
9	Krupiste	40	6.9	0.72	60–70	50–60	11.51	19.57
10	Negorci[a]	47–53	80	11.7	47–53	100–140	17.58	29.89
11	Podlog[a]	71–78	150–300	79.11	70–80	350–360	82.88	82.88
12	Proevci	31	2	0.13	50–60	40–50	7.53	12.81
13	Rakles	26	2	0.09	40–50	10–20	1.88	3.20
14	Sabota voda	21	5	0.13	50–60	40–60	8.37	14.23
15	Smokvica[a]	45–68	138	25.99	45–68	140–160	22.23	37.80
16	Strnovec	40	17	1.78	60–70	60–80	14.65	24.91
17	Strumica[b]	17–23	1–3		80–120	80–100	27.54	46.18
18	Shtip – Ldzi Kezovica	57–5953–60	4–810–15	1.082.14	50–60	30–4025–30	6.864.61	9.967.83
19	Tetovo Pena	30	10	0.63	35–45	10–15	1.31	2.22
	Total	17–78	620.6–857.6	**161.62**	40–120	1335–1820	**367.35**	**558.10**

[a] Good correlation with greenhouse production area (bold numbers emphasize the total available, expected and expected with reinjection geothermal heat capacity in Macedonia).
[b] Possible new location for development.

plastic constructions and which is similarly valid for expensive highly sophisticated equipment.

All the listed types of heating systems are easy acceptable in local conditions according to the previous experience. However, additional education is necessary for application of automatic regulation and defined schemes for timing the production.

7. Possibilities for geothermal energy application

Geothermal energy application for heating greenhouses is already proven in Macedonia and the world. It is possible to state its positive aspects but also the negative ones and existing limitations, i.e.:

- Geothermal energy is on disposal only locally, i.e. each use should be near the resource because transportation to longer distance is not economically feasible.
- Geothermal energy offers continual supply of heat, independently of the season or changes of outside climate conditions.
- Geothermal energy is environmentally benign energy source because the effluent water after its use (for any purpose) is re-injected back to the geothermal reservoir (aquifer).
- Geothermal fluid is normally high mineralized and often corrosive and with intention for scaling.
- Completion of the energy source is time consuming and expensive. Particular measures should be taken for protection against corrosion and scaling.
- After completion, supply of heat is nearly free of charge. Only pumping and maintenance costs appear in exploitation.

With all listed advantages and disadvantages, application of geothermal energy is already proved in Macedonia—technically and economically. There is already quite a long experiences in agriculture (heating greenhouses and warm water irrigation), for space heating (public buildings, medical institutions and spa facilities) and for medical spas. From the economic point of view, they are all profitable, even the most profitable in comparison with any other energy source, fossil fuels or RES. At last but not least, there is a wide market for supply the heat on disposal and eventual larger offer of new developed energy sources.

According to the available information (Table 1), development of new geothermal projects is economically feasible in many locations of the Eastern and South part of the country. Some of them are within the traditional regions with developed protected crop cultivation (Fig. 3). Practically, development of a new 30–40 ha geothermally heated complex of modern glasshouses and 30–40 ha soft plastic covered tunnels and greenhouses is possible and economically feasible, together with development of the residential heating, industrial uses and opening of new spa and recreational centres, during a period of 10 years.

8. Economy of wider geothermal energy introduction

Commercial feasibility of geothermal greenhouse heating depends on a number of factors, such as capital investment costs, operating costs, cost of energy with respect to the value of the product, and market available for the product. If we leave out all the factors that are common to any energy source, it is obvious that the crucial factor for estimating the commercial feasibility and competitiveness of geothermal energy is the price of the used heat. Final price of heat depends on factors such as capital investment required, credit conditions, maintenance and exploitation costs, insurance and taxes, labor costs, fuel prices, plant efficiency and utilization coefficient. Depending on the type of energy utilized and local conditions, characteristic curves can be plotted (Fig. 14) to show the dependence of the used heat price on the annual heat load factor (hours of utilization of the installed heat capacity) [4].

These curves will differ from case to case, but generally they show that geothermal energy is not economical for short utilization periods Real benefits can be attained if the available thermal power is used over longer periods of the year, i.e. geothermal energy is very convenient for covering the base heat demands (Fig. 13). It is more economical to meet peak demands with some other energy

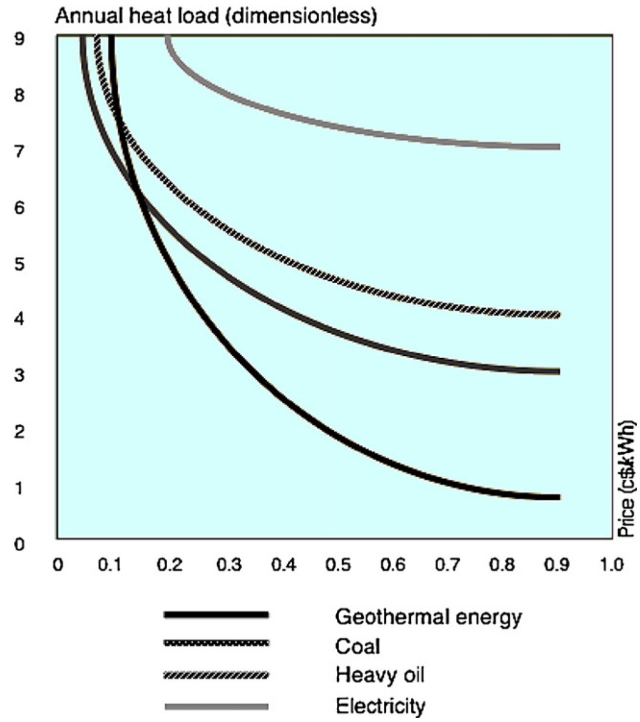

Fig. 14. Dependence of the price of produced heat from different heat sources on the annual heat loading factor [3].

that does not require high capital investments, even if exploitation costs are high.

As an example, Fig. 14 [3] reports an analysis of economic data for geothermal greenhouses located in Macedonia. The greenhouses cover 3 ha, with 6 MW of installed capacity; the geothermal well produces 50 l/s and the temperature regime for the heating installations is 70/40 °C. The analysis was made by determination of the price of used kWh of thermal energy for different loads during the year, for each of the listed fuels and geothermal energy.

Obviously, the largest changes are for the case of geothermal energy utilization as the heat source. If using geothermal energy for covering all the heat requirements over the year, annual heat loading factor is in the measures between 0.25 and 0.35, resulting with an average price of used heat of 3–4 US$¢/kWh. However, if the peak loadings are covered by some other energy source, heat loading factor goes to 0.5–0.6 with an average price of 1.5–2.0 US$¢/kWh.

The above mentioned prices and the table itself are valid only for the concrete case. Depending on costs for concrete geothermal energy source completion, conditions of financing, prices of other energy sources, etc. differences can appear. However, these differences shall not disturb general relation between the resulting prices of used heat. When is possible to reach higher values of the annual heat loading factor, geothermal energy is far the most competitive variant! That is enabling to organize competitive export orientated out-of-season production of vegetable and flowers.

The above statement in combination with the convenient market conditions and profitability of the winter production justify concentration of efforts for organization of a new development cycle. Its main advantage, beside the economical competiveness are the independence of the international energy market changes and absence of negative environmental impact. Both are of particular importance in correlation to the continual increase of prices of fossil fuels and electricity and increased attention to the human environment protection.

Development cycle in question shall increase employment in rural regions of the country, decrease the dependence of import of energy raw materials and shall increase the export of products.

9. Concluding remarks

Macedonia has been the main supplier of ex-Yugoslavian market with out-of-season vegetable production and partly of flowers (carnations and roses). Good part of the production has been exported to third countries, too. However, the political and economic transition process of the country during the last 20 years resulted with lost of the main markets and drastic decrease of the production. Only greenhouses, heated by geothermal energy survived without negative consequences.

Present first signs of stabilization of the economy of the country, followed with slow return of previous markets, underline the importance of revival of previous export orientated productions, like it was the protected crops cultivation. Recently realized studies and investigations resulted with positive possibilities and justifiableness of organization of modernization and new development of it, particularly when base on the cheap geothermal energy supply. Good market possibilities during the winter and early spring months enable economic feasibility of it. Normally, the process should be based on the results of a list of investigations and studies, in order to determine the best technical/technological solutions, accommodated to the locally influencing climate, market and economy factors. Unfortunately, state still does not show real interest to support it and the local private business sector is not developed and strong enough to take the responsibility for that, particularly when geothermal energy resource development is in question. It requires a rather long and expensive period for exploration and investigations, which makes it not interesting for the business sector looking for quick solutions.

According to the experience of more developed countries, which should be followed, development of a system of regulatory and finance measures for supporting elimination of the initial constraints can result with significant success in rather short periods. Organization of new development process of protected crop cultivation in Macedonia, based on wider geothermal energy use, deserve it because offering good profitability and increase of employment in poor rural areas and is not followed with negative impacts to the environment.

References

[1] Gorgieva M. Geothermal potential at the territory of the Republic of Macedonia (Fundamentals for the second resource assessment). In: U.S.A./MK project GEOMACAM, Skopje, Macedonia. 2002.
[2] Popovski K, Vasilevska SP. Heating greenhouses with geothermal energy. Renexpo Central & South-East Europe. In: 1st international conference: geothermal energy in Eastern Europe. Budapest, Hungary, April 20; 2007.
[3] Heating greenhouses with geothermal energy.Popovski K, Vasilevska SP, editors. Proceedings of the international workshop on heating greenhouses with geothermal energy. Ponta Delgada, Azores, Portugal. 1998, 450 pp.
[4] Engineering aspects of geothermal energy use in agriculture, guideline and textbook.Popovski K, editor. International summer school on direct application of geothermal energy, Skopje, Macedonia. 1991, 374 pp.
[5] Campiotti CA. Geothermal energy as sustainable energy resource in agriculture. International geothermal days "Greece 2002", Thessaloniki, Greece 2002.
[6] van den Braak NJ, Knies P. Waste heat for greenhouse heating in the Netherlands. In: First FAO/CNRE technical consultations' on geothermal energy and industrial thermal effluents use in agriculture, Rome; 1985.
[7] Boyd TL. Greenhouse and aquaculture information packages. In: International geothermal days "Greece 2002", Thessaloniki, Greece. 2002.
[8] Lund. JW. Introduction to geothermal greenhouse design. International geothermal days "Greece 2002", Thessaloniki, Greece 2002.
[9] Lineau PJ, Lunis BG. Geothermal direct use engineering and design guidebook, Chapter 15 Greenhouses. Klamath Falls, U.S.A.: Geo Heat Center; 1989. pp. 271–290.
[10] Popovski K. Simple heating methods for mild Mediterranean climate conditions. In: JSHS symposium on simple methods for heating and ventilating greenhouses in mild climate conditions, Djerba-Tozeur. 1988.
[11] Popovski K, Vasilevska SP. Geothermal energy in Europe: possibilities for more intensive development—what about further development of geothermal energy use in agriculture in Europe? Problems and possibilities. In: ISS International geothermal days Poland 2002, Zakopane, Poland. 2002.

[12] Popovski K, Vasilevska SP. Geothermal energy use in Macedonia. State-of-the art and experience of agricultural uses. In: International summer school on geothermal geochemistry, Izmir, Turkey. 2003.
[13] Popovski K. Integrated geothermal district heating systems—benefits and problems. In: International summer school on geothermal geochemistry, Izmir, Turkey. 2003.
[14] Popovski K, Vasilevska SP. Heating greenhouses with geothermal energy. International geothermal days "Greece 2002", Thessaloniki, Greece 2002.
[15] Popovski K, Vasilevska SP, Micevski E, Naunov J. Heating greenhouses with geothermal energy. Renexpo Central & South-East Europe. In: Macedonia country update 2007 first signs of recovery. Unterchahing, Germany, May 29–June 2; 2007.
[16] Popovski K, Micevski E, Gecevska V, Vasilevska SP. Geothermal energy in Macedonia. Skopje: Publication of MAGA; 2010.
[17] Rafferty KD, Greenhouse construction. Course notes on heating with geothermal energy: conventional and new schemes. Lienau PJ, Convenor, WGC2000 short course, Japan. Pisa, Italy: International School of Geothermics, pp. 143–156.
[18] Rafferty KD. Fossil fuel-fired peak heating for geothermal greenhouses. U.S. Department of Energy. Office of Geothermal Technologies; December 1996.
[19] von Zabeltitz C. Gewachshauser handhuch des erwerhgartners. Stuttgart: EV Vertag Eugen Ulmer; 1986.